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Lake Madison, Lake County South Dakota

National Eutrophication Survey, Corvallis, Oreg

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Corvallis Environmental Research Lab, Oreg

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16. ABSTRACT

Annual total phosphorus and total nitrogen loadings to the lake were estimated and subdivided according to either point or non-point source origin. An assessment of the lake's trophic condition and limiting nutrient is also provided. All data collected by the U.S.E.P.A. National Eutrophication Survey during the one year study of the lake and its tributaries are included in the report.

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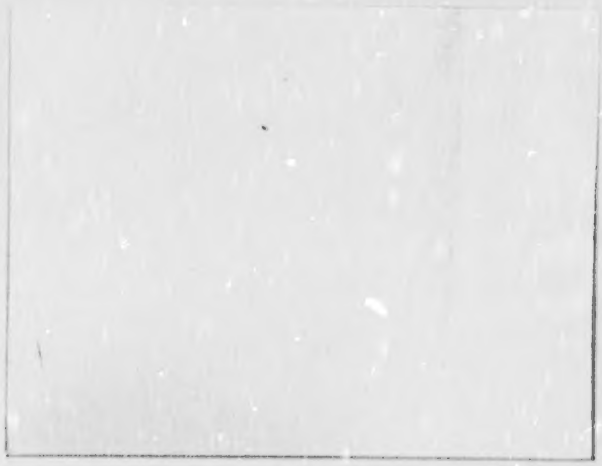

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REPORT
ON
LAKE MADISON
LAKE COUNTY
SOUTH DAKOTA
EPA REGION VIII
WORKING PAPER No. 612

WITH THE COOPERATION OF THE
SOUTH DAKOTA DEPARTMENT OF ENVIRONMENTAL PROTECTION
AND THE
SOUTH DAKOTA NATIONAL GUARD

JANUARY, 1977

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FOREWORD

The National Eutrophication Survey was initiated in 1972 in response to an Administration commitment to investigate the nationwide threat of accelerated eutrophication to freshwater lakes and reservoirs.

OBJECTIVES

The Survey was designed to develop, in conjunction with state environmental agencies, information on nutrient sources, concentrations, and impact on selected freshwater lakes as a basis for formulating comprehensive and coordinated national, regional, and state management practices relating to point-source discharge reduction and non-point source pollution abatement in lake watersheds.

ANALYTIC APPROACH

The mathematical and statistical procedures selected for the Survey's eutrophication analysis are based on related concepts that:

a. A generalized representation or model relating sources, concentrations, and impacts can be constructed.

b. By applying measurements of relevant parameters associated with lake degradation, the generalized model can be transformed into an operational representation of a lake, its drainage basin, and related nutrients.

c. With such a transformation, an assessment of the potential for eutrophication control can be made.

LAKE ANALYSIS

In this report, the first stage of evaluation of lake and watershed data collected from the study lake and its drainage basin is documented. The report is formatted to provide state environmental agencies with specific information for basin planning [§303(e)], water quality criteria/standards review [§303(c)], clean lakes [§314(a,b)], and water quality monitoring [§106 and §305(b)] activities mandated by the Federal Water Pollution Control Act Amendments of 1972.

Beyond the single lake analysis, broader based correlations between nutrient concentrations (and loading) and trophic condition are being made to advance the rationale and data base for refinement of nutrient water quality criteria for the Nation's freshwater lakes. Likewise, multivariate evaluations for the relationships between land use, nutrient export, and trophic condition, by lake class or use, are being developed to assist in the formulation of planning guidelines and policies by EPA and to augment plans implementation by the states.

ACKNOWLEDGMENT

The staff of the National Eutrophication Survey (Office of Research & Development, U. S. Environmental Protection Agency) expresses sincere appreciation to the South Dakota Departments of Environmental Protection and Game, Fish and Parks for professional involvement, to the South Dakota National Guard for conducting the tributary sampling phase of the Survey, and to those wastewater treatment plant operators who voluntarily provided effluent samples.

Allyn Lockner, Secretary, and Blaine Barker and Duane Murphy, Department of Environmental Quality; Douglas Hansen, Department of Game, Fish and Parks; and James Hayden, Director, State Lakes Preservation Committee provided invaluable lake documentation and counsel during the Survey, reviewed the preliminary reports, and provided critiques most useful in the preparation of this Working Paper series.

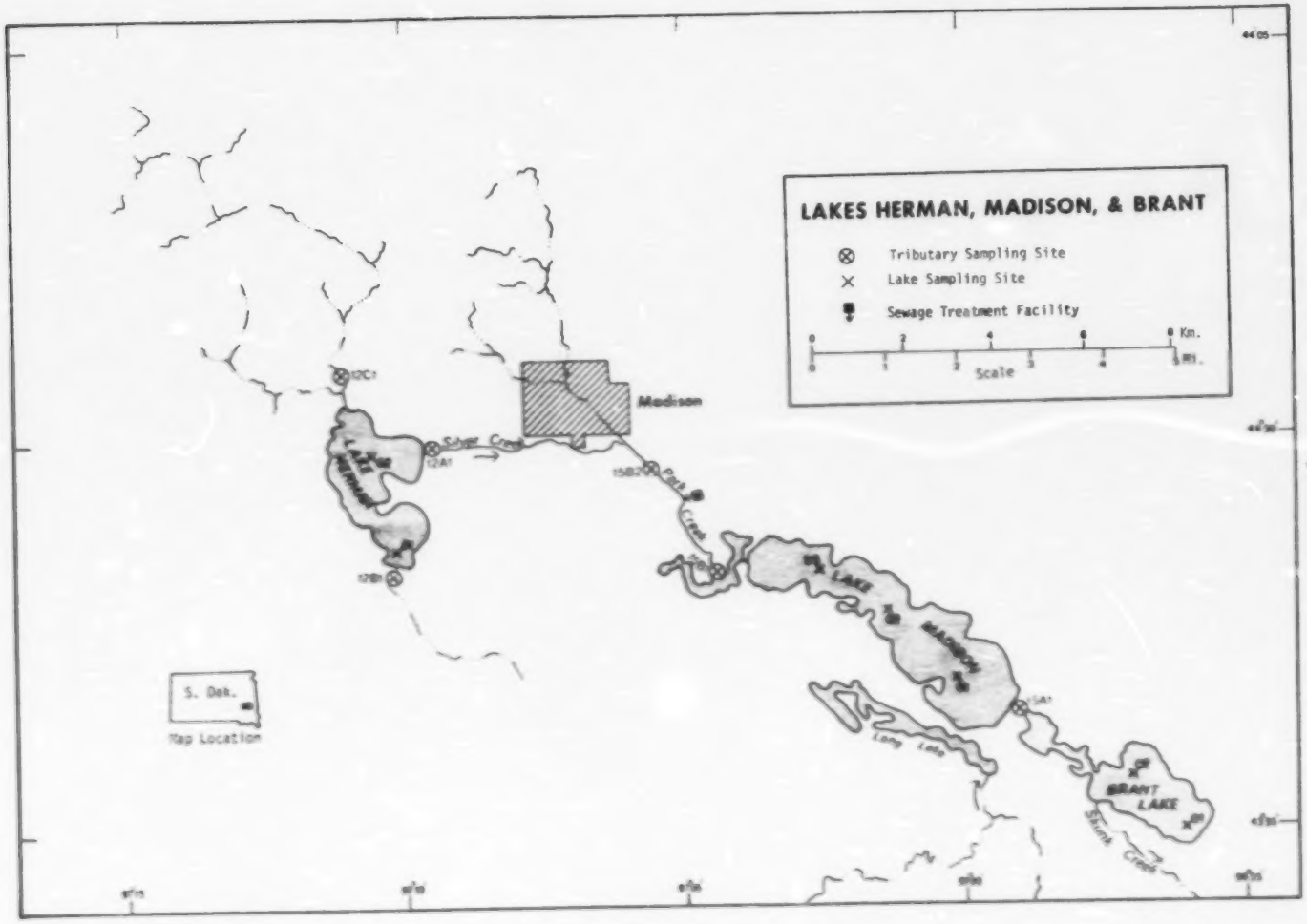
Major General Duane L. Corning, the Adjutant General of South Dakota, and Project Officer Colonel Robert D. Chalberg, who directed the volunteer efforts of the South Dakota National Guardsmen, are also gratefully acknowledged for their assistance to the Survey.

NATIONAL EUTROPHICATION SURVEY

STUDY LAKES

STATE OF SOUTH DAKOTA

LAKE NAME	COUNTY
Albert	Kingsbury
Alvin	Lincoln
Angostura	Fall River
Brant	Lake
Byron	Beadle
Clear	Marshall
Clear	Minnehaha
Cochrane	Deuel
Cottonwood	Spink
Deerfield	Pennington
Enemy Swim	Day
Herman	Lake
John	Hamlin
Kampeska	Codington
Madison	Lake
Mitchell	Davidson
Norden	Hamlin
East Oakwood	Brookings
West Oakwood	Brookings
Pactola	Pennington
Pickerel	Day
Poinsett	Brookings, Lake
Red Iron South	Marshall
Richmond	Brown
Roy	Marshall
Sand	Brown
Sheridan	Pennington
Stockdale	Custer
East Vermillion	McCook
Wall	Minnehaha
Waubay	Day


LAKES HERMAN, MADISON, & BRANT
Tributary Sampling Site
Lake Sampling Site
Sewage Treatment Facility
Scale
Km.
Mi.
Madison
Silver Creek
Spring Creek
LAKE HERMAN
LAKE MADISON
Long Lake
BRANT LAKE
Skunk Creek
S. Dak.
Map Location

LAKE MADISON

STORET NO. 4615

I. CONCLUSIONS

A. Trophic Condition:

Survey data indicate that Lake Madison is eutrophic. It ranked eighteenth in overall trophic quality when the 31 South Dakota lakes sampled in 1974 were compared using a combination of six water quality parameters*. Twenty-two of the lakes had less median total phosphorus, twenty-one had less median dissolved orthophosphorus, seven had less median inorganic nitrogen, 14 had less mean chlorophyll a, and 14 had greater Secchi disc transparency. Depression of dissolved oxygen with depth occurred at station 2 in July.

Survey limnologists noted beds of submerged macrophytes in July and September and blooms of algae in September. Heavy algal blooms, sometimes causing unpleasant odors, usually occur in the lake in July and August (Brashier et al., 1973).

B. Rate-Limiting Nutrient:

The algal assay results indicate the lake was limited by nitrogen in April and September. The lake data indicate nitrogen limitation at all sampling times.

C. Nutrient Controllability:

1. Point sources--During the year of sampling, the City of Madison wastewater treatment plant contributed 51.3% of the

* See Appendix A.

total phosphorus load to Lake Madison, and lakeshore septic tanks contributed an estimated 1.2% of the total. The proportion of the total phosphorus load attributed to the City of Madison probably was greater during the year of sampling than would be the case during a normal or average year because of low stream flows in the sampling year (see page 9).

The phosphorus loading of 0.73 g/m^2 measured during the sampling year is 7.3 times that proposed by Vollenweider (Vollenweider and Dillon, 1974) as a eutrophic loading (see page 13). It is calculated that even complete removal of phosphorus at the Madison treatment plant, or effluent diversion, would result in a phosphorus load of 0.36 $g/m^2/yr$, or nearly four times the eutrophic loading. While such removal or diversion might reduce the incidence and severity of nuisance algal blooms, primary production in Lake Madison presently is markedly nitrogen-limited (N/P ratios = 5/1 or less; see page 8), and it does not seem likely that phosphorus removal at the Madison plant would cause a shift to a phosphorus-limited condition in the lake, particularly in view of the fact that upstream Lake Herman*, which is eutrophic but not impacted by point-source nutrients, is also nitrogen-limited (N/P ratios = 3/1 or less).

2. Non-point sources--The phosphorus contributions of non-

* Working Paper No. 609.

point sources amounted to 47.5% of the total phosphorus load during the sampling year. Park Creek contributed 45.0% of the total, and the ungaged minor tributaries and immediate drainage contributed an estimated 0.1%.

The phosphorus export rate of Park Creek was a high 16 kg/km^2 during the sampling year. In part, this may have resulted from an underestimation of the Madison treatment plant load; however, the treatment plant data (Appendix E) appear to be typical of the degree of treatment provided. Also, note that the phosphorus concentrations in Park Creek at station B-1 were consistently higher than those in the upstream treatment plant effluent.

The high export rate of Park Creek at least in part probably was due to agricultural runoff. In a previous report, it is noted that feedlots in the drainage contribute to the nutrient loads to lake Madison (Brashier et al., op. cit.).

II. LAKE AND DRAINAGE BASIN CHARACTERISTICS†

A. Lake Morphometry††:

1. Surface area: 11.33 kilometers^2.
2. Mean depth: 3.0 meters.
3. Maximum depth: 6.1 meters.
4. Volume: 33.990 x 10^6 m^3.
5. Mean hydraulic retention time: 10.9 years.

B. Tributary and Outlet:
(See Appendix C for flow data)

1. Tributaries -

Name	Drainage area (km^2)*	Mean flow (m^3/sec)*
Park Creek (at B-1)	235.7	0.090
Minor tributaries & immediate drainage -	63.8	0.009
Totals	299.5	0.099

2. Outlet -

Unnamed Stream A-1	310.8**	0.099

C. Precipitation***:

1. Year of sampling: 51.6 centimeters.
2. Mean annual: 61.8 centimeters.

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† Table of metric conversions--Appendix B.
†† Murphey, 1974.
* For limits of accuracy, see Working Paper No. 175, "...Survey Methods, 1973-1976".
** Includes area of lake.
*** See Working Paper No. 175.

III. LAKE WATER QUALITY SUMMARY

Lake Madison was sampled three times during the open-water season of 1974 by means of a pontoon-equipped Huey helicopter. Each time, samples for physical and chemical parameters were collected from two or more depths at three stations on the lake (see map, page v). During each visit, a single depth-integrated (near bottom to surface) sample was composited from the stations for phytoplankton identification and enumeration; and during the first and last visits, a single 18.9-liter depth-integrated sample was composited for algal assays. Also each time, a depth-integrated sample was collected from each of the stations for chlorophyll a analysis. The maximum depths sampled were 2.7 meters at stations 1 and 2 and 2.1 meters at station 3.

The sampling results are presented in full in Appendix D and are summarized in the following table.

A. SUMMARY OF PHYSICAL AND CHEMICAL CHARACTERISTICS FOR MADISON LAKE
STORET CODE 4615

PARAMETER	1ST SAMPLING (4/23/74) 3 SITES RANGE	MEAN	MEDIAN	2ND SAMPLING (7/12/74) 3 SITES RANGE	MEAN	MEDIAN	3RD SAMPLING (9/20/74) 3 SITES RANGE	MEAN	MEDIAN
TEMP (C)	10.0 - 10.6	10.3	10.2	24.8 - 26.6	25.6	25.5	16.5 - 16.7	16.6	16.6
DISS OXY (MG/L)	10.6 - 10.8	10.8	10.8	3.0 - 10.0	4.8	3.5	8.2 - 8.8	8.6	8.6
CNDCTVY (MCROMO)	1169. - 1209.	1197.	1194.	1755. - 1817.	1775.	1770.	1455. - 1468.	1462.	1461.
PH (STAND UNITS)	8.4 - 8.5	8.5	8.5	8.4 - 8.8	8.6	8.6	8.8 - 8.8	8.8	8.8
TOT ALK (MG/L)	165. - 166.	165.	165.	160. - 167.	164.	164.	148. - 152.	150.	151.
TOT P (MG/L)	0.092 - 0.123	0.103	0.099	0.548 - 0.724	0.619	0.603	0.232 - 0.270	0.248	0.246
ORTHO P (MG/L)	0.013 - 0.016	0.015	0.015	0.400 - 0.582	0.460	0.451	0.091 - 0.112	0.104	0.106
NO2+NO3 (MG/L)	0.030 - 0.060	0.042	0.035	0.050 - 0.070	0.059	0.060	0.020 - 0.020	0.020	0.020
AMMONIA (MG/L)	0.020 - 0.050	0.032	0.030	1.130 - 1.670	1.381	1.385	0.030 - 0.040	0.035	0.035
KJEL N (MG/L)	1.300 - 1.400	1.367	1.400	3.200 - 4.000	3.587	3.600	2.300 - 2.600	2.450	2.400
INORG N (MG/L)	0.050 - 0.110	0.073	0.065	1.190 - 1.730	1.440	1.450	0.050 - 0.060	0.055	0.055
TOTAL N (MG/L)	1.340 - 1.460	1.408	1.430	3.250 - 4.060	3.646	3.665	2.320 - 2.620	2.470	2.420
CHLRPYL A (UG/L)	11.9 - 17.1	14.0	12.9	0.4 - 3.4	1.5	0.7	50.5 - 55.5	52.3	50.8
SECCHI (METERS)	1.2 - 1.2	1.2	1.2	1.8 - 3.0	2.5	2.7	0.3 - 0.4	0.4	0.4

B. Biological characteristics:

1. Phytoplankton -

Sampling Date	Dominant Genera	Algal Units per ml
04/23/74	1. Flagellates	58,722
	2. Chroomonas sp.	2,812
	3. Ankistrodesmus sp.	1,930
	4. Oscillatoria sp.	827
	5. Kirchneriella sp.	607
	Other genera	2,150
	Total	67,048
07/12/74	1. Aphanizomenon sp.	720
	2. Schroederia sp.	48
	Total	768
09/20/74	1. Aphanizomenon sp.	10,641
	2. Phormidium sp.	1,205
	3. Actinastrum sp.	683
	4. Cyclotella sp.	642
	5. Oscillatoria sp.	522
	Other genera	2,931
	Total	16,624

2. Chlorophyll a -

Sampling Date	Station Number	Chlorophyll a (µg/l)
04/23/74	1	12.9
	2	11.9
	3	17.1
07/12/74	1	0.7
	2	0.4
	3	3.4
09/20/74	1	50.5
	2	50.8
	3	55.5

C. Limiting Nutrient Study:

1. Autoclaved, filtered, and nutrient spiked -

a. April sample -

Spike (mg/l)	Ortho P Conc. (mg/l)	Inorganic N Conc. (mg/l)	Maximum yield (mg/l-dry wt.)
Control	0.030	0.036	1.7
0.050 P	0.080	0.036	1.6
0.050 P + 1.0 N	0.080	1.036	27.1
1.0 N	0.030	1.036	16.5

b. September sample -

Spike (mg/l)	Ortho P Conc. (mg/l)	Inorganic N Conc. (mg/l)	Maximum yield (mg/l-dry wt.)
Control	0.108	0.162	4.7
0.050 P	0.158	0.162	5.3
0.050 P + 1.0 N	0.158	1.162	22.4
1.0 N	0.108	1.162	19.0

2. Discussion -

The control yields of the assay alga, Selenastrum capricornutum, indicate that the potential primary productivity of Lake Madison was moderately high at the times the samples were collected (04/23/74 and 09/20/74). Also, significant increases in yields with the addition of nitrogen alone indicate that the lake was nitrogen limited at those times. Note that the addition of phosphorus alone did not result in yields significantly greater than the control yields.

The lake data also indicate nitrogen limitation; i.e., the mean inorganic nitrogen/orthophosphorus ratios were 5/1 or less at all sampling times.

IV. NUTRIENT LOADINGS
(See Appendix E for data)

For the determination of nutrient loadings, the South Dakota National Guard collected monthly near-surface grab samples from each of the tributary sites indicated on the map (page v). Sampling was begun in October, 1974, and was completed in September, 1975.

Through an interagency agreement, stream flow estimates for the year of sampling and a "normalized" or average year were provided by the South Dakota District Office of the U.S. Geological Survey for the tributary sites nearest the lake.

Because the Park Creek flows measured by U.S.G.S. at station B-1 (N = 15) were about 40% less than normal, the relatively constant Madison treatment plant effluent flows accounted for about half of the stream flow during the sampling year.

Under the above conditions, it would be expected that phosphorus concentrations in the stream at station B-1 would be higher than usual during the sampling year, and this appears to be the case, although few comparable data are available. Brashier et al. (1973) sampled Park Creek at station B-1 four times in 1970. The mean of the total phosphorus concentrations in their samples was 2.11 mg/l (range of 0.61 to 3.44 mg/l), whereas the mean of the ten Survey samples was 4.64 (range of 1.10 to 10.80)

For the above reasons, the Survey data are not representative of a normal or average year, so the nutrient loads shown are for the year of sampling and were calculated using the mean of measured daily flows

and the mean nutrient concentrations. It is recognized that this results in the point-source loads comprising a greater proportion of the total loads than would be the case in a normal year.

Nutrient loads for the ungaged "minor tributaries and immediate drainage" ("ZZ" of U.S.G.S.) were estimated using the mean concentrations in Park Creek at station B-2 and the mean annual ZZ flow.

There were no measurable flows in the outlet stream at station A-1, and no samples were collected during the sampling year. Therefore, essentially all of the nutrient inputs to the lake were retained during the year of sampling.

The operator of the Madison wastewater treatment plant provided monthly composited effluent samples and corresponding flow data.

A. Waste Sources:

1. Known municipal* -

Name	Pop. Served	Treatment	Mean Flow (m^3/d)	Receiving Water
Madison	6,315	tr. filter + pond	2,408.5	Park Creek

2. Known industrial - None

* Treatment plant questionnaire.

B. Annual Total Phosphorus Loading - Year of Sampling:

1. Inputs -

Source	kg P/ yr	% of total
a. Tributaries (non-point load) -		
Park Creek (at B-1)	3,720	45.0
b. Minor tributaries & immediate drainage (non-point load) -	10	0.1
c. Known municipal STP's -		
Madison	4,245	51.3
d. Septic tanks* -	95	1.2
e. Known industrial - None	-	-
f. Direct precipitation** -	200	2.4
Total	8,270	100.0

2. Outputs -

Lake outlet - Unnamed Stream A-1 -

3. Net annual P accumulation - 8,270 kg.

* Estimate based on 334 shoreline dwellings; see Working Paper No. 175.
** See Working Paper No. 175.

C. Annual Total Nitrogen Loading - Year of Sampling:

1. Inputs -

Source	kg N/yr	% of total
a. Tributaries (non-point load) -		
Park Creek (at B-1)	13,165	33.3
b. Minor tributaries & immediate drainage (non-point load) -	195	0.5
c. Known municipal STP's -		
Madison	10,395	26.3
d. Septic tanks* -	3,560	9.0
e. Known industrial - None	-	-
f. Direct precipitation** -	12,230	30.9
Total	39,545	100.0

2. Outputs -

Lake outlet - Unnamed Stream A-1 -

3. Net annual N accumulation - 39,545 kg.

D. Mean Annual Non-point Nutrient Export by Subdrainage Area:

Tributary	kg P/km^2/yr	kg N/km^2/yr	N/P ratio
Park Creek (at B-1)	16	56	3.5/1

* Estimate based on 334 shoreline dwellings; see Working Paper No. 175.
** See Working Paper No. 175.

E. Yearly Loads:

In the following table, the existing phosphorus loadings are compared to those proposed by Vollenweider (Vollenweider and Dillon, 1974). Essentially, his "dangerous" loading is one at which the receiving water would become eutrophic or remain eutrophic; his "permissible" loading is that which would result in the receiving water remaining oligotrophic or becoming oligotrophic if morphometry permitted. A mesotrophic loading would be considered one between "dangerous" and "permissible".

Note that Vollenweider's model may not be applicable to water bodies with short hydraulic retention times.

	Total Phosphorus		Total Nitrogen	
	Total	Accumulated	Total	Accumulated
grams/m^2/yr	0.73	0.73	3.5	3.5

Vollenweider phosphorus loadings ($g/m^2/yr$) based on mean depth and mean hydraulic retention time of Lake Madison:	
"Dangerous" (eutrophic loading)	0.10
"Permissible" (oligotrophic loading)	0.05

V. LITERATURE REVIEWED

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VI. APPENDICES

APPENDIX A

LAKE RANKINGS

LAKE DATA TO BE USED IN RANKINGS

LAKE CODE	LAKE NAME	MEDIAN TOTAL P	MEDIAN INORG N	500-MEAN SEC	MEAN CHLORA	15-MIN DO	MEDIAN DISS ORTHO P
4601	LAKE ALBERT	0.321	0.170	489.111	106.289	9.200	0.019
4602	ALVIN LAKE	0.067	0.970	442.833	4.700	9.400	0.017
4603	ANGOSTURA RESERVOIR	0.019	0.160	423.333	3.717	13.000	0.005
4604	BRANT LAKE	0.194	0.130	432.833	34.150	11.800	0.113
4605	LAKE BYRON	0.443	0.370	488.333	149.350	9.000	0.146
4606	CLEAR LAKE	0.027	0.075	430.167	11.983	8.800	0.009
4607	CLEAR LAKE	1.400	0.270	495.333	691.000	7.000	0.468
4608	COCHRANE LAKE	0.037	0.150	446.000	15.683	15.000	0.008
4609	COTTONWOOD LAKE	0.685	0.265	490.333	112.017	8.600	0.417
4610	DEERFIELD RESERVOIR	0.033	0.080	303.333	3.650	15.000	0.022
4611	ENEMY SWIM LAKE	0.037	0.085	442.600	14.200	8.200	0.013
4612	LAKE HERMAN	0.340	0.155	485.000	58.733	8.600	0.174
4613	ST JOHN LAKE	0.348	0.080	489.400	120.880	9.800	0.025
4614	LAKE KAMPESKA	0.220	0.105	468.889	20.567	8.200	0.128
4615	MADISON LAKE	0.250	0.090	445.555	22.578	14.000	0.107
4616	LAKE MITCHELL	0.099	0.085	465.833	14.883	13.800	0.015
4617	LAKE NORDEN	0.256	0.165	488.667	46.800	10.000	0.050
4618	OAKWOOD LAKE EAST	0.146	0.175	487.000	113.600	10.000	0.009
4619	OAKWOOD LAKE WEST	0.181	0.135	485.833	159.667	9.600	0.021
4620	PACTOLA RESERVOIR	0.011	0.070	248.444	1.478	11.000	0.006
4621	PICKEREL LAKE	0.049	0.095	439.833	15.833	9.600	0.009
4622	LAKE POINSETT	0.115	0.315	468.444	40.211	10.000	0.023
4623	LAKE RED IRON SOUTH	0.042	0.110	430.333	6.883	7.600	0.010
4624	RICHMOND LAKE	0.187	0.150	410.000	18.467	10.000	0.144
4625	ROY LAKE	0.034	0.070	431.000	13.333	11.000	0.010
4626	SAND LAKE	0.489	0.110	471.800	65.740	12.800	0.288
4627	SHERIDAN LAKE	0.053	0.105	394.000	15.433	15.000	0.016
4628	STOCKADE LAKE	0.233	0.150	432.000	25.400	15.000	0.109

LAKE DATA TO BE USED IN RANKINGS

LAKE CODE	LAKE NAME	MEDIAN TOTAL P	MEDIAN INORG N	500-MEAN SEC	MEAN CHLORA	15-MIN DO	MEDIAN DISS ORTHO P
4629	LAKE VERMILLION	0.211	0.100	472.833	10C.800	9.200	0.092
4630	WALL LAKE	0.194	0.160	441.667	55.267	7.400	0.076
4631	WAUBAY LAKE NORTH	0.098	0.145	469.555	127.033	11.400	0.023

PERCENT OF LAKES WITH HIGHER VALUES (NUMBER OF LAKES WITH HIGHER VALUES)

LAKE CODE	LAKE NAME	MEDIAN TOTAL P	MEDIAN INORG N	500-MEAN SEC	MEAN CHLORA	15-MIN DO	MEDIAN DISS ORTHO P	INDEX NO
4601	LAKE ALBERT	20 (6)	20 (6)	10 (3)	23 (7)	68 (20)	60 (18)	201
4602	ALVIN LAKE	67 (20)	0 (0)	57 (17)	90 (27)	63 (19)	63 (19)	340
4603	ANGOSTURA RESERVOIR	97 (29)	30 (9)	87 (26)	93 (28)	20 (6)	100 (30)	427
4604	BRANT LAKE	40 (12)	53 (16)	70 (21)	47 (14)	27 (8)	23 (7)	260
4605	LAKE BYRON	10 (3)	3 (1)	17 (5)	7 (2)	73 (22)	13 (4)	123
4606	CLEAR LAKE	93 (28)	93 (28)	83 (25)	83 (25)	77 (23)	90 (27)	519
4607	CLEAR LAKE	0 (0)	10 (3)	0 (0)	0 (0)	100 (30)	0 (0)	110
4608	COCHRANE LAKE	83 (25)	40 (11)	50 (15)	67 (20)	5 (0)	93 (28)	338
4609	COTTONWOOD LAKE	3 (1)	13 (4)	3 (1)	20 (6)	82 (24)	3 (1)	124
4610	DEERFIELD RESERVOIR	90 (27)	88 (26)	97 (29)	97 (29)	5 (0)	53 (16)	430
4611	ENEMY SWIM LAKE	80 (24)	82 (24)	60 (18)	77 (23)	88 (26)	73 (22)	460
4612	LAKE HERMAN	17 (5)	33 (10)	27 (8)	33 (10)	82 (24)	10 (3)	202
4613	ST JOHN LAKE	13 (4)	88 (26)	7 (2)	13 (4)	53 (16)	43 (13)	217
4614	LAKE KAMPESKA	33 (10)	65 (19)	40 (12)	57 (17)	88 (26)	20 (6)	303
4615	MADISON LAKE	27 (8)	77 (23)	53 (16)	53 (16)	13 (4)	30 (9)	253
4616	LAKE MITCHELL	60 (18)	82 (24)	47 (14)	73 (22)	17 (5)	70 (21)	349
4617	LAKE NORDEN	23 (7)	23 (7)	13 (4)	40 (12)	45 (12)	40 (12)	184
4618	OAKWOOD LAKE EAST	53 (16)	17 (5)	20 (6)	17 (5)	45 (12)	85 (25)	237
4619	OAKWOOD LAKE WEST	50 (15)	50 (15)	23 (7)	3 (1)	58 (17)	57 (17)	241
4620	PACTOLA RESERVOIR	100 (30)	98 (29)	100 (30)	100 (30)	35 (10)	97 (29)	530
4621	PICKEREL LAKE	73 (22)	73 (22)	67 (20)	63 (19)	58 (17)	85 (25)	419
4622	LAKE POINSETT	57 (17)	7 (2)	43 (13)	43 (13)	45 (12)	47 (14)	242
4623	LAKE RED IRON SOUTH	77 (23)	58 (17)	80 (24)	87 (26)	93 (28)	78 (23)	473
4624	RICHMOND LAKE	47 (14)	40 (11)	90 (27)	60 ([illegible]	45 (12)	17 (5)	299
4625	ROY LAKE	87 (26)	98 (29)	77 (23)	80 (24)	35 (10)	78 (23)	455
4626	SAND LAKE	7 (2)	58 (17)	33 (10)	30 (9)	23 (7)	7 (2)	158
4627	SHERIDAN LAKE	70 (21)	65 (19)	93 (28)	70 (21)	5 (0)	67 (20)	370
4628	STOCKADE LAKE	30 (9)	40 (11)	73 (22)	50 (15)	5 (0)	27 (8)	225

PERCENT OF LAKES WITH HIGHER VALUES (NUMBER OF LAKES WITH HIGHER VALUES)

LAKE CODE	LAKE NAME	MEDIAN TOTAL P	MEDIAN INORG N	500-MEAN SEC	MEAN CHLORA	15-MIN DO	MEDIAN DISS ORTHO P	INDEX NO
4629	LAKE VERMILLION	37 (11)	70 (21)	30 (9)	27 (8)	68 (20)	33 (10)	265
4630	WALL LAKE	43 (13)	27 (8)	63 (19)	37 (11)	97 (29)	37 (11)	304
4631	WAUBAY LAKE NORTH	63 (19)	47 (14)	37 (11)	10 (3)	30 (9)	50 (15)	237

LAKES RANKED BY INDEX NOS.

RANK	LAKE CODE	LAKE NAME	INDEX NO
1	4620	PACTOLA RESERVOIR	530
2	4606	CLEAR LAKE	519
3	4623	LAKE RED IRON SOUTH	473
4	4611	ENEMY SWIM LAKE	460
5	4625	ROY LAKE	455
6	4610	DEERFIELD RESERVOIR	430
7	4603	ANGOSTURA RESERVOIR	427
8	4621	PICKEREL LAKE	419
9	4627	SHERIDAN LAKE	370
10	4616	LAKE MITCHELL	349
11	4602	ALVIN LAKE	340
12	4608	COCHRANE LAKE	338
13	4630	WALL LAKE	304
14	4614	LAKE KAMPESKA	303
15	4624	RICHMOND LAKE	299
16	4629	LAKE VERMILLION	265
17	4604	BRANT LAKE	260
18	4615	MADISON LAKE	253
19	4622	LAKE POINSETT	242
20	4619	OAKWOOD LAKE WEST	241
21	4631	WAUBAY LAKE NORTH	237
22	4618	OAKWOOD LAKE EAST	237
23	4628	STOCKADE LAKE	225
24	4613	ST JOHN LAKE	217
25	4612	LAKE HERMAN	202
26	4601	LAKE ALBERT	201
27	4617	LAKE NORDEN	184
9	4626	SAND LAKE	158

LAKES RANKED BY INDEX NOS.

RANK	LAKE CODE	LAKE NAME	INDEX NO
29	4609	COTTONWOOD LAKE	124
30	4605	LAKE BYRON	123
31	4607	CLEAR LAKE	110

CONVERSION FACTORS

Hectares x 2.471 = acres

Kilometers x 0.6214 = miles

Meters x 3.281 = feet

Cubic meters x 8.107×10^{-4} = acre/feet

Square kilometers x 0.3861 = square miles

Cubic meters/sec x 35.315 = cubic feet/sec

Centimeters x 0.3937 = inches

Kilograms x 2.205 = pounds

Kilograms/square kilometer x 5.711 = lbs/square mile

APPENDIX C

TRIBUTARY FLOW DATA

TRIBUTARY FLOW INFORMATION FOR SOUTH DAKOTA 05/03/76

LAKE CODE 4615 MADISON

TOTAL DRAINAGE AREA OF LAKE(SQ KM) 310.8

TRIBUTARY	SUB-DRAINAGE AREA(SQ KM)	NORMALIZED FLOWS(CMS) JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
4615A1	310.8	0.028	0.028	0.028	0.255	0.340	0.198	0.142	0.057	0.028	0.028	0.028	0.028	0.099
461581	235.7	0.028	0.028	0.057	0.227	0.283	0.170	0.113	0.057	0.028	0.028	0.028	0.028	0.090
461582	233.1	0.028	0.028	0.057	0.227	0.283	0.170	0.113	0.057	0.028	0.028	0.028	0.028	0.090
4615ZZ	75.1	0.0	0.0	0.0	0.057	0.028	0.028	0.0	0.0	0.0	0.0	0.0	0.0	0.009

SUMMARY

TOTAL DRAINAGE AREA OF LAKE = 310.8
SUM OF SUB-DRAINAGE AREAS = 543.9

TOTAL FLOW IN = 2.27
TOTAL FLOW OUT = 1.19

MEAN MONTHLY FLOWS AND DAILY FLOWS(CMS)

TRIBUTARY	MONTH	YEAR	MEAN FLOW	DAY	FLOW	DAY	FLOW	DAY	FLOW
4615A1	10	74	0.0	11	0.0				
	11	74	0.0	2	0.0				
	12	74	0.0	7	0.0				
	1	75	0.0	18	0.0				
	2	75	0.0	8	0.0				
	3	75	0.0	1	0.0				
	4	75	0.0	12	0.0				
	5	75	0.0	30	0.0				
	6	75	0.0	9	0.0	23	0.0		
	7	75	0.0	13	0.0	26	0.0		
	8	75	0.0	25	0.0				
	9	75	0.0	6	0.0				
461581	10	74	0.023	12	0.023				
	11	74	0.023	2	0.023				
	12	74	0.020	7	0.017				
	1	75	0.023	18	0.023				
	2	75	0.014	8	0.008				
	3	75	0.023	1	0.020				
	4	75	0.023	12	0.023				
	5	75	0.071	18	0.085	30	0.085		
	6	75	0.085	9	0.085	23	0.085		
	7	75	0.099	13	0.085	26	0.085		
	8	75	0.085	25	0.085				
	9	75	0.071	6	0.085				

TRIBUTARY FLOW INFORMATION FOR SOUTH DAKOTA 05/03/76

LAKE CODE 4615 MADISON

MEAN MONTHLY FLOWS AND DAILY FLOWS(CMS)

TRIBUTARY	MONTH	YEAR	MEAN FLOW	DAY	FLOW	DAY	FLOW	DAY	FLOW
461582	10	74	0.000	12	0.000				
	11	74	0.000	2	0.000				
	12	74	0.0	7	0.0				
	1	75	0.0	18	0.0				
	2	75	0.0	8	0.0				
	3	75	0.0	1	0.0				
	4	75	0.003	12	0.003				
	5	75	0.004	18	0.004	30	0.004		
	6	75	0.003	9	0.003	23	0.003		
	7	75	0.003	13	0.003	26	0.003		
	8	75	0.003	25	0.003				
	9	75	0.003	6	0.001				
4615ZZ	10	74	0.0						
	11	74	0.0						
	12	74	0.0						
	1	75	0.0						
	2	75	0.0						
	3	75	0.0						
	4	75	0.014						
	5	75	0.014						
	6	75	0.014						
	7	75	0.0						
	8	75	0.0						
	9	75	0.0						

APPENDIX D

PHYSICAL and CHEMICAL DATA

STORET RETRIEVAL DATE 76/05/03

461501
44 56 57.0 097 00 03.0 3
MADISON L 'KE
46079 SOUTH DAKOTA

090791

11EPALES 2111202
0011 FEET DEPTH CLASS 00

DATE FROM TO	TIME OF DAY	DEPTH FEET	00010 WATER TEMP CENT	00300 DO MG/L	00077 TRANSP SECCHI INCHES	00094 CNDUCTVY FIELD MICROMHO	00400 PH SU	00410 T ALK CACO3 MG/L	00610 NH3-N TOTAL MG/L	00625 TOT KJEL N MG/L	00630 NO2&NO3 N-TOTAL MG/L	00671 PHOS-DIS ORTHO MG/L P
74/04/23	15 05 0000		10.1		48	1194	8.40	165	0.050	1.400	0.060	0.016
	15 05 0002		10.1			1194						
	15 05 0008		10.0	10.6		1189	8.40	165	0.020	1.400	0.030	0.015
74/07/12	15 45 0000		25.9	3.4	72	1775	8.80	167	1.140	3.200	0.050	0.441
	15 45 0003		25.7	10.0		1775	8.70	166	1.130	3.200	0.060	0.414
	15 45 0007		25.4	6.2		1760	8.70	163	1.150	3.200	0.060	0.400
74/09/20	10 30 0000		16.5	8.8	16	1461	8.81	151	0.030	2.400	0.020K	0.112
	10 30 0009		16.5	8.6		1455	8.83	151	0.040	2.400	0.020K	0.107

DATE FROM TO	TIME OF DAY	DEPTH FEET	00665 PHOS-TOT MG/L P	32217 CHLRPHYL A UG/L	00031 INCDT LT REMNING PERCENT
74/04/23	15 05 0000		0.092	12.9	
	15 05 0008		0.102		
74/07/12	15 45 0000		0.598	0.7	
	15 45 0003		0.548		
	15 45 0007		0.600		
	15 45 0011				1.0
74/09/20	10 30 0000		0.232	50.5	
	10 30 0002				50.0
	10 30 0004				5.0
	10 30 0005				1.0
	10 30 0009		0.244		

K VALUE KNOWN TO BE
LESS THAN INDICATED

STORET RETRIEVAL DATE 76/05/03

461502
44 57 42.0 097 01 16.0 3
MADISON LAKE
46079 SOUTH DAKOTA

090791

11EPALES 2111202
0011 FEET DEPTH CLASS 00

DATE FROM TO	TIME OF DAY	DEPTH FEET	00010 WATER TEMP CENT	00300 DO MG/L	00077 TRANSP SECCHI INCHES	00094 CNDUCTVY FIELD MICROMHO	00400 PH SU	00410 T ALK CACO3 MG/L	00610 NH3-N TOTAL MG/L	00625 TOT KJEL N MG/L	00630 NO2&NO3 N-TOTAL MG/L	00671 PHOS-DIS ORTHO MG/L P
74/04/23	15 20	0000	10.3		48	1190	8.50	166	0.020	1.400	0.030	0.015
	15 20	0002	10.3	10.8		1196						
	15 20	0008	10.2	10.8		1193	8.50	165	0.040	1.300	0.060	0.015
74/07/12	15 30	0000	26.6	6.0	120	1792	8.60	160	1.330	3.500	0.060	0.434
	15 30	0003	25.4	3.4		1764	8.60	164	1.650	4.000	0.060	0.582
	15 30	0007	24.8	3.2		1755	8.40	165	1.540	3.900	0.050	0.464
74/09/20	10 10	0000	16.6	8.6	17	1461	8.83	152	0.040	2.600	0.020K	0.105
	10 10	0009	16.5	8.2		1460	8.83	150	0.030	2.400	0.020K	0.107

DATE FROM TO	TIME OF DAY	DEPTH FEET	00665 PHOS-TOT MG/L P	32217 CHLRPHYL A UG/L	00031 INCDT LT REMNING PERCENT
74/04/23	15 20	0000	0.097	11.9	
	15 20	0008	0.096		
74/07/12	15 30	0000	0.606	0.4	
	15 30	0003	0.666		
	15 30	0007	0.724		
	15 30	0011			1.0
74/09/20	10 10	0000	0.241	50.8	
	10 10	0002			50.0
	10 10	0004			5.0
	10 10	0005			1.0
	10 10	0009	0.252		

K VALUE KNOWN TO BE
LESS THAN INDICATED

STORET RETRIEVAL DATE 76/05/03

461503
44 58 20.0 097 02 36.0 3
MADISON LAKE
46079 SOUTH DAKOTA
090791

11EPALES 2111202
0009 FEET DEPTH CLASS 00

DATE FROM TO	TIME OF DAY	DEPTH FEET	00010 WATER TEMP CENT	00300 DO MG/L	00077 TRANSP SECCHI INCHES	00094 CNDUCTVY FIELD MICROMHO	00400 PH SU	00410 T ALK CACO3 MG/L	00610 NH3-N TOTAL MG/L	00625 TOT KJEL N MG/L	00630 NO2&NO3 N-TOTAL MG/L	00671 PHOS-DIS ORTHO MG/L P
74/04/23	15	35 0000	10.6	10.8	48	1209	8.50	165	0.040	1.300	0.040	0.014
	15	35 0005	10.6	10.8		1208	8.50	166	0.020	1.400	0.030	0.013
74/07/12	15	10 0000	25.7	3.0	108	1817	8.40	163	1.670	4.000	0.060	0.485
	15	10 0005	25.1	3.6		1760	8.60	162	1.440	3.700	0.070	0.462
74/09/20	10	00 0000	16.7	8.6	13	1468	8.80	150	0.040	2.600	0.020K	0.091
	10	00 0007	16.6	8.6		1467	8.80	148	0.030	2.300	0.020K	0.105

DATE FROM TO	TIME OF DAY	DEPTH FEET	00665 PHOS-TOT MG/L P	32217 CHLRPHYL A UG/L	00031 INCDT LT REMNING PERCENT
74/04/23	15	35 0000	0.109	17.1	
	15	35 0005	0.123		
74/07/12	15	10 0000	0.632	3.4	
	15	10 0005	0.580		
	15	10 0009			1.0
74/09/20	10	00 0000	0.248	55.5	
	10	00 0002			50.0
	10	00 0003			5.0
	10	00 0004			1.0
	10	00 0007	0.270		

K VALUE KNOWN TO BE
LESS THAN INDICATED

APPENDIX E

TRIBUTARY AND WASTEWATER TREATMENT PLANT DATA

STORET RETRIEVAL DATE 76/05/04

461581
43 58 22.0 097 04 18.0 4
PARK CREEK
46 7.5 LK MADISON
T/MADISON LAKE 091292
SD HWY 19 BRDG 3.5 MI SE OF MADISON
11EPALES 2111204
0000 FEET DEPTH CLASS 00

DATE FROM TO	TIME OF DAY	DEPTH FEET	00630 NO2&NO3 N-TOTAL MG/L	00625 TOT KJEL N MG/L	00610 NH3-N TOTAL MG/L	00671 PHOS-DIS ORTHO MG/L P	00665 PHOS-TOT MG/L P
74/10/12	09 13		0.264	10.000	6.900	1.950	4.000
74/11/02	14 00		0.905	13.000	9.700	3.600	4.600
74/12/07	14 45		5.580	15.000	12.000	4.070	5.200
75/02/08	15 00		0.025	28.000	21.000	7.900	10.800
75/03/01	13 40		0.950	22.000	19.500	6.400	9.700
75/04/12	14 20		2.100	3.200	1.650	1.150	1.250
75/05/18	13 30		0.800	7.920	5.200	2.050	
75/05/30	10 15		1.000	6.400	4.600	2.500	2.700
75/06/09	11 00		0.680	5.500	3.150	1.570	2.600
75/07/13	13 15		0.690	3.700		0.740	1.100
75/07/26	15 30		0.085	23.000	4.300	2.700	4.400

STORET RETRIEVAL DATE 76/05/04

461582
43 59 33.0 097 05 32.0 4
PARK CREE
46 7.5 LK MADISON
T/MADISON LAKE 091292
BANK SAMP' E JUST ABOVE MADISON STP
11EPALES 2111204
0000 FEET DEPTH CLASS 00

DATE FROM TO	TIME OF DAY	DEPTH FEET	00630 NO2&NO3 N-TOTAL MG/L	00625 TOT KJEL N MG/L	00610 NH3-N TOTAL MG/L	00671 PHOS-DIS ORTHO MG/L P	00665 PHOS-TOT MG/L P
74/10/12	08 45		0.016	0.700	0.095	0.012	0.060
74/11/02	14 20		0.008	0.500	0.075	0.015	0.040
75/04/12	14 30		0.065	1.150	0.340	0.015	0.055
75/05/18	13 00		0.010	0.400	0.103	0.010	0.035
75/05/30	10 00		0.005	0.300	0.110	0.010	0.010
75/06/09	11 30		0.045	1.515	0.620	0.045	
75/06/23	13 00		0.020	0.450	0.100	0.025	0.040
75/07/13	13 30		0.010	0.300	0.055	0.010	0.040
75/07/26	15 00		0.005	0.700	0.060	0.005	0.050
75/09/06	14 30		0.050	0.700	0.055	0.015	0.060

STORET RETRIEVAL DATE 76/05/04

46158A TF46158A P006315
43 59 30.0 097 05 30.0 4
MADISON
46 7.5 LAKE MADISON
T/LAKE MADISON 091292
PARK CREEK
11EPALES 2141204
0000 FEET DEPTH CLASS 00

DATE FROM TO	TIME OF DAY	DEPTH FEET	00630 NO2&NO3 N-TOTAL MG/L	00625 TOT KJEL N MG/L	00610 NH3-N TOTAL MG/L	00671 PHOS-DIS ORTHO MG/L P	00665 PHOS-TOT MG/L P	50051 FLOW RATE INST MGD	50053 CONDUIT FLOW-MGD MONTHLY
75/01/22	09 00								
CP(T)-			3.120	18.000	0.400K		9.700	0.512	0.520
75/01/22	15 00								
75/02/25	09 00								
CP(T)-			0.080		0.470			0.528	0.510
75/02/26	09 00								
65/03/18	09 00								
CP(T)-			2.640	14.000		8.000	8.000	0.637	0.550
75/03/18	03 00								
75/04/16	09 00								
CP(T)-			1.650	8.500	0.780	4.700	4.700	0.815	0.675
75/04/17	03 00								
75/05/13	09 00								
CP(T)-			1.100	8.600	0.250	3.600	3.600	0.800	0.750
75/05/14	03 00								
75/06/04	09 00								
CP(T)-			1.550	10.500	0.160	3.000	4.000	0.700	0.700
75/06/05	03 00								
75/07/01	09 00								
CP(T)-			0.225	10.500	2.100	2.030	2.500	0.728	0.690
75/07/02	03 00								
75/08/27	09 00								
CP(T)-			0.875	5.100	0.025K	1.375	2.900	0.822	0.750
75/08/28	03 00								
75/09/16	09 00								
CP(T)-			0.825	9.200	0.100	1.450	2.300	0.719	0.650
75/09/17	03 00								
75/10/08	09 00								
CP(T)-			1.500	8.200	0.025K	3.400	4.500	0.650	0.625
75/10/08	20 00								
75/11/03	08 00								
CP(T)-			2.880	9.700	0.425	4.300	4.700	0.694	0.650
75/11/03	20 00								
75/12/03	09 00								
CP(T)-			6.300	8.000	3.900	5.400	5.400	0.566	0.550
75/12/03	19 00								

K VALUE KNOWN TO BE
LESS THAN INDICATED

STORET RETRIEVAL DATE 76/05/04

46158A TF46158A P006315
43 59 30.0 097 05 30.0 4
MADISON
46 7.5 LAKE MADISON
T/LAKE MADISON 091292
PARK CREEK
11EPALES 2141204
0000 FEET DEPTH CLASS 00

DATE FROM TO	TIME OF DAY	DEPTH FEET	00630 NO2&NO3 N-TOTAL MG/L	00625 TOT KJEL N MG/L	00610 NH3-N TOTAL MG/L	00671 PHOS-DIS ORTHO MG/L P	00665 PHOS-TOT MG/L P	50051 FLOW RATE INST MGD	50053 CONDUIT FLOW-MGD MONTHLY
76/01/13	08 00			10.000		7.900	8.700	0.567	0.525
CP(T)-									
76/01/13	19 00								